BELLCOMM, INC.
1100 Seventeenth Street, N.W. Washington, D. C. 20036

SUBJECT: Scientific Evaluation of Alternative ATM Missions at High Inclination - Case 630

DATE: August 6, 1968

FROM: D. B. Wood

ABSTRACT

Consideration of the scientific goals of the five solar astronomy experiments on the ATM and evaluation of a set of possible high inclination alternative missions to the workshop cluster show that, among these alternatives,

1. the best mission at a given inclination and duration is one with launch date nearest the solar maximum,

2. the best mission at a given launch date is one with the longest duration,

3. the best mission for a summer solstice launch and given duration is one which is highly inclined and eccentric.

If the ATM can be launched by June 1971, then the workshop cluster mission is best because of its 56-day duration even with the planned low inclination (28.5°). If the workshop must be appreciably postponed (beyond early 1972), then a decoupled high inclination mission (in summer 1971) becomes the best 28-day duration substitute. Desirable decoupled 28-day alternatives to a delayed workshop are

1.	50°	inclination	150 x 580 n.mi.
2.	50°	inclination	150 x 400 n.mi.
3.	50°	inclination	375 n.mi.
4.	63.5°	inclination	150 x 300 n.mi.
5.	63.5°	inclination	225 n.mi.

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MEMORANDUM FOR FILE

I. INTRODUCTION

An earlier memorandum(1) evaluated the scientific advantages of a Solar Apollo Telescope Mount (ATM) mission at 50° inclination. It showed that there was little, if any, gain due to increased solar viewing in a low circular orbit at that inclination over one at 28½°. This memorandum extends the study, based on further information on this solar cycle and on the interests of the principal investigators, to consider the relationship between scientific goals and a set of alternative mission modes that would also be possible with the Saturn IB launch capabilities. This set is representative of the best missions attainable in low earth orbit with the exception of sun-synchronous retrograde missions which are not possible from Cape Kennedy. It addresses the question of what are the best alternative missions if the workshop cluster cannot accommodate the ATM in 1971. The experiments assumed throughout are the five currently envisioned solar astronomy experiments listed in tabular form below.

NASA Expt. No.	Sponsoring Institution	Principal Investigator
S-052	High Altitude Observatory	G. Newkirk
S-053/S-082	Naval Research Laboratory	J. D. Purcell
S-054	American Science & Engineer'g	R. Giacconi
S-055/S-083	Harvard College Observatory	L. Goldberg
S-056	Goddard Space Flight Center	J. Milligan

The constraints imposed upon mission parameters by the launch and spacecraft capabilities are detailed elsewhere.(6)

II. EARTH'S ATMOSPHERE

During the course of any solar ATM mission the sun will be repeatedly occulted or nearly occulted by the earth. The earth, as an occulter, has an effective radius slightly larger than its physical radius due to its atmosphere. This effective radius depends upon the degree of optical interference acceptable to the experiments involved. Figure 1 shows the geometry involved in observing tangent to the earth. Table I shows the difference in total mass of interfering air column along a viewing direction straight up through the atmosphere from a given height and looking tangent to that same height from outside the atmosphere. Tabulated are the values of air mass per unit column area normalized to the value looking toward the zenith from the surface of the earth. We see that the amount of air is 25 to 80 times greater horizontally than vertically. This air mass interferes with astronomical observations in various ways discussed below. Note that this atmospheric interference is only important when the line of sight to the sun grazes the atmosphere, which occurs only for short intervals during most orbits. Atmospheric effects are unimportant on the sun-side of the earth at altitudes over a few hundred kilometers as long as the line of sight to the sun is well above the horizon.

A. Scattered Light

The earth's atmosphere scatters sunlight by the Rayleigh process at very high altitudes. This scattering varies directly as the air mass. The amount of scattered sunlight is only very slightly dependent upon the spacecraft altitude, since the spacecraft is generally high enough so that the remaining atmosphere gives insignificant scattering. It has been shown[2] that light scattered by spacecraft effluents is probably not important. Figure 2 shows the amount of scattered sunlight as a function of atmospheric height and wavelength for a line of sight tangent to the atmosphere at that height for sun angle 0°. The intensity of light, $B/B_\odot$, is expressed in units of the solar intensity. The Newkirk White-Light Coronograph experiment is to measure out to six solar radii, where $B/B_\odot$ is 10^{-10}. From this figure we conclude that the scattered light looking tangent to the atmosphere at 100 km altitude (looking close to the sun) is almost identical in intensity to that of the solar corona at six solar radii at 4000 Å.

B. Absorption

The earth's atmosphere is a very good absorber of ultraviolet radiation. Absorption varies exponentially with the air mass. If 90% absorption* is the lowest acceptable cut-off point for the experimenters, then Figure 3 shows approximately the effective atmospheric height as a function of wavelength at the worst case - looking tangent to the atmosphere. The two UV experiments on the ATM, S-055 (S-083) and S-053 (S-082), cover primarily the region of maximum atmospheric absorption between 300 and 1400 Å. For these experiments, the atmosphere is effectively 300 km high, assuming that 90% absorption is acceptable. For the longer wavelength UV and for S-056 and S-054 the effective atmosphere drops to about 150 to 170 km.

C. Emissions[3]

The earth's atmosphere gives rise to two types of emission important to consider for the solar mission: dayglow and aurora.

Dayglow emissions extend from about 80 to 700 km in height. The strongest emissions, in order of height, are NaD (5893 Å) at 90 km, Lyman-Alpha (1216 Å) and OI (1304 Å) at about 120 km, and N_2^+ (3914 Å), OI (5577 Å and 6300 Å) at about 300 km. Of possible importance to observations of the solar corona in white light are the visible light emissions originating at 300 km altitude. While it is difficult to predict the magnitude or likelihood of this interference, we should allow now for the chance that each source of sufficient altitude could interfere. The effective earth atmosphere for the coronograph experiment could thus be raised from 100 km based on scattering to about 300 km because of the dayglow. The UV emissions occur below the height limit imposed by absorption.

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*The assumption here is that such a large amount of absorption could be calibrated out for the short times involved, since most of the solar observations will be made well on the sunlit side with essentially zero absorption. The 90% absorption simply represents the point at which we assume we start receiving data coming into the sunlight, or stop getting data when going into the night.

Auroral emissions range between 100 and 1100 km in height. Sunlit aurora are normally at an altitude of about 300 km. The maximum intensity is at a geomagnetic latitude of 68°, which corresponds to a geophysical latitude of between 54 and 78°. Hence, any orbit inclined 54° or more, or any orbit that requires looking over the earth at these latitudes (as would be the case with a 50° orbit), is apt to encounter auroral activity. The actual auroral emissions of importance are the same as the dayglow emissions except that the aurora is generally considerably more intense. Since the aurora generally occur at about 300 km, we see that again the effective atmosphere is near 300 km, although aurora could occur even above the spacecraft, especially in the year or two following solar maximum.

III. SCIENTIFIC OBJECTIVES[4]

All principal investigators are concerned about continued postponement of the ATM-A, since each year past the solar maximum means less and less solar activity. Some, e.g. Giacconi (S-054), say that any further slippage of the schedule beyond early 1971 would "seriously degrade" the scientific value. At the other extreme, Newkirk's experiment (S-052) is not strongly dependent on the level of solar activity.

In general, all experiments would profit from solar activity during the observation period. In particular, all would profit from actual solar flare observations. However, each experiment (including S-054) is capable of making great contributions to our understanding of solar physics regardless of the level of solar activity. The ATM-A experiments represent a spatial resolution capability of about a factor of 10 over the OSO satellites. Because of the great variety of solar activity possible at any time during the solar cycle, each experimenter has had to consider the possibility of observing few flares even at solar maximum. Hence, each experiment is designed to yield important data over any range of solar activity. Dr. Milligan (S-056) has stated the situation quite well when he says "We can only observe what the sun permits us to see. One can only design his equipment for a large range of solar activity and hope that the sun will be kind."

All experimenters have indicated that the mission duration must be at least one solar rotation (about 28 days) in order to follow the evolution of active solar regions.

The broad scientific objectives impacted by orbital constraints can be summarized briefly as

A. observe the sun for a mission duration of at least 28 days,

B. observe the sun at the highest possible level of activity, and

C. observe the sun for the longest possible integrated viewing time.

Objective A is extremely important. The best compromise with Objectives B and C would be to observe the sun so that the product of activity and observing time is largest, thus yielding the highest chance of flare observation.

IV. SOLAR ACTIVITY

The previous memorandum[(1)] established that flare activity will probably decrease by about a factor of two between late 1970 and early 1972, and that the expected flare rate (Class 2 or greater) in late 1970 is about 2 in 2½ days. The solar cycle, as it has progressed to date, shows evidence of being below average in activity.[(5)] The expected flare rate (Class 2 or greater) in late 1970 is now predicted to be about 0.5 in 2½ days, and as previously indicated, half that in early 1972. Recent statistics indicate that only about 10% of all solar flares are of Class 2 or greater. Figure 4 shows the probability of observation of solar flares for the predicted rates. One time scale applies to total observing time with no earth occultation. The other time scale is for 60% sunlit time, which is typical for a low-inclination orbit at about 230 n.mi. We see, for example, that the probability of seeing one or more Class 2 flares in late 1970 in eight days of 100% sunlit unocculted viewing (the longest available unocculted period achieved by this set of high inclination orbits) is about 0.55. To achieve this same probability in 1972 with no unocculted viewing (i.e., low inclination) would require a mission duration three and one-half times longer. Also from this figure we see that if the workshop cluster mission were to be postponed from mid-1971 to early 1972, the flare probability would drop from .92 to .81. We will use the information from Figure 4 for the mission comparisons below.

V. ALTERNATIVE MISSIONS

Now we consider the impact upon the scientific objectives of various alternative mission parameters.

A. Inclination

In terms of the impact upon the science, we can consider four broad categories of inclinations (at low orbital altitude):

(1) Any low inclination, presumably near 28.5°.

(2) Near-50° inclination, where the sun is just marginally unocculted for a few days.

(3) Any orbit with an inclination greater than about 60° and less than 90°, where the sun spends an appreciable time interval unocculted. For discussion in this memo we will consider an inclination of 63.5°, which has the unique property that the line of apsides does not precess.

(4) Any high-inclination retrograde orbit designed to be sun-synchronous, and hence offering year-round uninterrupted solar viewing.

Case (4) will not be considered at this time because such an orbit is not now possible launching from Cape Kennedy. The main emphasis here is to discuss the relative merits of high inclination orbits [Case (2) or (3)] of 28-day duration as compared with the cluster mission at 28.5° [Case (1)].

B. Orbital Height

For there to be any unocculted period of reasonable duration, the orbital height must be considerably above the effective atmosphere height, which for most experiments is 300 km. This height is necessary when the telescope must "peer over" the earth to see the sun (see Figure 5). By using an eccentric orbit and locating apogee where the atmosphere offers the least obstruction to viewing, we can, for a given launch capability, gain the advantage of a high orbit but with a smaller semimajor axis. It is important to avoid the South Atlantic anomaly as much as possible due to radiation effects on crew and film, and this requires locating the perigee in the southern hemisphere. The special "marginal occulting" near 50° inclination [Case (2) above] becomes less distinct from higher inclinations [Case (3)] when we consider eccentric orbits. The sun spends an appreciable time unocculted in an orbit inclined 50° when the orbit is not circular but elliptical.

C. Mission Duration

It is of utmost importance, scientifically, to observe one complete solar rotation (about 28 days). Hence a mission less than about 28 days has serious scientific drawbacks. A 28-day mission with six days of continuous 100% viewing (such as provided by an inclination of 63.5°) has an aggregate actual observing time of about 20 days spread over the 28 days. From Figure 4 we see that such a mission is comparable in total observation, for the same level of flare activity, to a 33-day mission at 28.5° inclination (60% sun time).

VI. EVALUATION OF ALTERNATIVES

For solar observation we are interested in, from Section III, the following three criteria:

(1) observing one solar rotation (28 days),

(2) observing as many total hours as possible (integrated viewing time, whether interrupted or not), and

(3) having some chance of observing flares by maximizing the product of total viewing hours times flare rate.

In the previous memorandum,(1) it was shown that 100% unocculted viewing offers little advantage in flare observations, since the typical time duration of the entire flare, and certainly of the most interesting portion, the rise time, is comparable to or short of the 56-minute unocculted period of even low inclination orbits.

Point (1) establishes a minimum for mission duration. Of course we can watch a part of the sun complete one rotation as long as we exceed 14 days mission duration. Point (2) says that at any given inclination we want the longest possible mission. Point (3) says that we want the mission to be as early as possible to yield a larger flare probability.

In Section V.B we discussed orbital altitude. The advantage of an eccentric orbit, with perigee in the southern hemisphere, was pointed out. At 50° inclination there is only one such possible orbit per year, near the summer solstice. At 63.5° inclination, a winter solstice launch is also possible.

Consider the following alternative missions, which have been selected as feasible under the constraints of booster capability for the ATM-A mission and with acceptable radiation dosage:

(1) S-IV B workshop cluster mission - 225 n.mi. circular orbit inclined 28.5° for a duration of 56 days.

(2) Decoupled 28.5° circular mission - 225 n.mi. circular orbit inclined 28.5° for a duration of 28 days.

(3) Decoupled high eccentricity mission - 150 x 580 n.mi. orbit inclined 50° for a duration of 28 days.

(4) Decoupled low eccentricity mission - 150 x 400 n.mi. orbit inclined 50° for a duration of 28 days. This orbit, unlike all other alternatives, may be attained with only 2 stages instead of "2½".

(5) Decoupled 50° circular mission - 375 n.mi. circular orbit inclined 50° for a duration of 28 days.

(6) Decoupled high inclination eccentric mission - 150 x 300 n.mi. orbit inclined 63.5° for a duration of 28 days.

(7) Decoupled high inclination circular mission - 225 n.mi. circular orbit inclined 63.5° for a duration of 28 days.

(8) 56-day eccentric mission - 150 x 400 n.mi. orbit inclined 50°.

Now we can construct a matrix of alternative missions (1) through (8) versus the evaluation criteria (1) through (3) above. Such a matrix is shown in Table II, where each column has the following significance:

Column 1 - Criterion (1), the number of solar rotations during the mission.

Column 2 - Criterion (2), the total integrated viewing time in days.

Column 3 - Criterion (3), the product of viewing time times flare rate. The tabular entries represent the actual number of flares observable if they occur at the predicted rate.

Column 4 - Related to Criterion (3), this is the probability of observing one or more Class 2 flares during the entire mission.

Column 5 - Total number of contiguous unocculted viewing days.

Column 6 - Probability of observing one or more Class 2 flares during this unocculted period.

Columns 3, 4 and 6 are based on the predicted flare rate at the summer solstice of 1971. If launch is postponed to the winter solstice, the comparable values are given in Table III. The 50° elliptical orbits [missions (3), (4), and (8)] are not useful in the winter because no unocculted viewing is possible.

Inspection of Tables II and III and Figure 4 shows the following significant points:

(1) The best mission at a given inclination and duration is one with the earliest launch date. Since high inclination orbits must be "tuned" to a solstice, such launch dates are quantized to one per year (summer) or two per year (summer and winter).

(2) The best mission at a given launch date is one with the longest duration rather than a high inclination.

(3) The best mission at a given date and duration is one which is highly inclined and possibly eccentric. Inclination increase alone does not help a circular orbit unless the inclination is in excess of about 60°.

Point (1) above probably cannot be met any earlier than June 1971. Point (2) indicates that a given date, e.g. June 1971, a 56-day mission, even the low-inclination cluster mission, is better than any mission of 28 days. Point (3) indicates that for a given duration, e.g. 28 days, the best mission is one that maximizes viewing time by a suitable combination of orbital inclination and eccentricity. To this end, any of the 50° or 63.5° alternatives are better than a 23.5° 28-day mission.

As mentioned in the previous memorandum,[1] the coronograph experiment may be affected by sunlight scattered by the earth into the instrument even though the earth's atmosphere is not actually in the solar corona. This is serious in the 50° circular mission where for several days the sun is within a few degrees of the effective horizon. The other orbit affected is the 50° low eccentricity (150 x 400 n.mi.) orbit; but even though the sun gets as close as 4° to the horizon, 45 minutes later in the same orbit it is 19° from the horizon, so the coronograph experiment is no worse off than it would be in any periodically occulting orbit.

VII. SUMMARY

The scientific objectives of the ATM-A mission are best met if

A. mission duration is at least 28 days, and

B. the probability of flare observation is maximized, i.e., the product of integrated viewing time and flare probability is maximized.

Item A is one obvious mission constraint. Item B is dependent on various mission parameters. The product may be increased by

(1) launching as early in the solar cycle as possible,

(2) extending the mission duration as long as possible, or

(3) obtaining the maximum viewing time possible per orbit (i.e., 100% for as long as possible).

If the workshop cluster mission [which satisfies (2) above] cannot accommodate the ATM in 1971 [thus not satisfying (1) above] then the best alternative mission for the ATM is one which maximizes viewing time in reduced mission duration [satisfying (3) above]. All five alternative high inclination 28-day missions considered herein provide this additional viewing time, no one alternative standing out far above any other on the basis of scientific merit. These five are comparable to a 56-day 28.5° mission in early 1972 and better than any 28-day 28.5° mission possible in 1971.

A 56-day 50° mission in the summer of 1971 satisfies (1), (2), and (3) above, affording the greatest amount of solar viewing of any mission possible from Cape Kennedy.

D. B. Wood

1015-DBW-caw D. B. Wood

Attachments
  References
  Tables I-III
  Figures 1-5

REFERENCES

(1) Wood, D. B., "Scientific Considerations of an Early, Decoupled ATM Mission at an Inclination of 50°," Bellcomm Memorandum for File, June 5, 1968.

(2) Buffalano, C., A Review of the Optical Environment Problem for the ATM-A Mission," Bellcomm Memorandum for File, June 6, 1968.

(3) McCormac, B. M. (editor), 1967, Aurora and Airglow, (Reinhold Publishing Corporation, New York.

(4) Forsyth, D. L., private communication of replies of principal investigators to NASA telegram of May 9, 1968.

(5) Prince, H. D., letter to H. Glaser, NASA/SG, dated June 4, 1968.

(6) Martersteck, K. E. and Hirsch, I., 1968, "Payload Performance for High Inclination Decoupled LEM/ATM Mission," Bellcomm Memorandum for File (to be issued).

HEIGHT (KM)	VERTICAL FROM HEIGHT	HORIZONTAL, TANGENT TO HEIGHT
0	1	76
100	3.2×10^{-7}	2.6×10^{-5}
150	6.0×10^{-9}	2.1×10^{-7}
200	1.3×10^{-9}	4.9×10^{-8}
250	4.5×10^{-10}	1.4×10^{-8}
300	1.9×10^{-10}	4.6×10^{-9}

TABLE I - APPROXIMATE VALUES OF AIRMASS FOR VERTICAL AND HORIZONTAL VIEWING AT VARIOUS ALTITUDES

TABLE 2

EVALUATION OF ALTERNATIVE MISSIONS FOR SUMMER SOLSTICE OF 1971.

MISSION	(1) SOLAR ROTATIONS	(2) INTEGRATED VIEWING (DAYS)	(3) VIEWING X FLARE RATE	(4) FLARE PROBABILITY	(5) UNOCCULTED PERIOD (DAYS)	(6) UNOCCULTED FLARE PROBABILITY
1 WORKSHOP CLUSTER (28.5°)	2	32.4	4.86	.92	0	0
2 28.5° CIRCULAR	1	16.3	2.45	.71	0	0
3 50° HIGH ELLIPTICAL	1	21.7	3.26	.81	8	.45
4 50° LOW ELLIPTICAL	1	19.9	2.98	.78	5	.31
5 50° CIRCULAR	1	21.0	3.15	.80	5	.31
6 63.5° ELLIPTICAL	1	20.0	3.00	.78	6	.36
7 63.5° CIRCULAR	1	19.9	2.98	.73	6	.36
8 56-DAY (50°) ELLIPTICAL	2	36.3	5.44	.94	5	.31

TABLE 3

EVALUATION OF ALTERNATIVE MISSIONS FOR WINTER SOLSTICE OF 1971

MISSION	(1) SOLAR ROTATIONS	(2) INTEGRATED VIEWING (DAYS)	(3) VIEWING X FLARE RATE	(4) FLARE PROBABILITY	(5) UNOCCULTED PERIOD (DAYS)	(6) UNOCCULTED FLARE PROBABILITY
1 WORKSHOP CLUSTER (28.5°)	2	32.4	3.64	.84	0	0
2 28.5° CIRCULAR	1	16.3	1.82	.60	0	0
3 50° HIGH ELLIPTICAL	-	-	-	-	-	-
4 50° LOW ELLIPTICAL	-	-	-	-	-	-
5 50° CIRCULAR	1	21.0	2.36	.69	5	.2
6 63.5° ELLIPTICAL	1	20.0	2.25	.67	6	.28
7 63.5° CIRCULAR	1	19.9	2.23	.67	6	.28
8 56-DAY (50°) ELIPTICAL	-	-	-	-	-	-

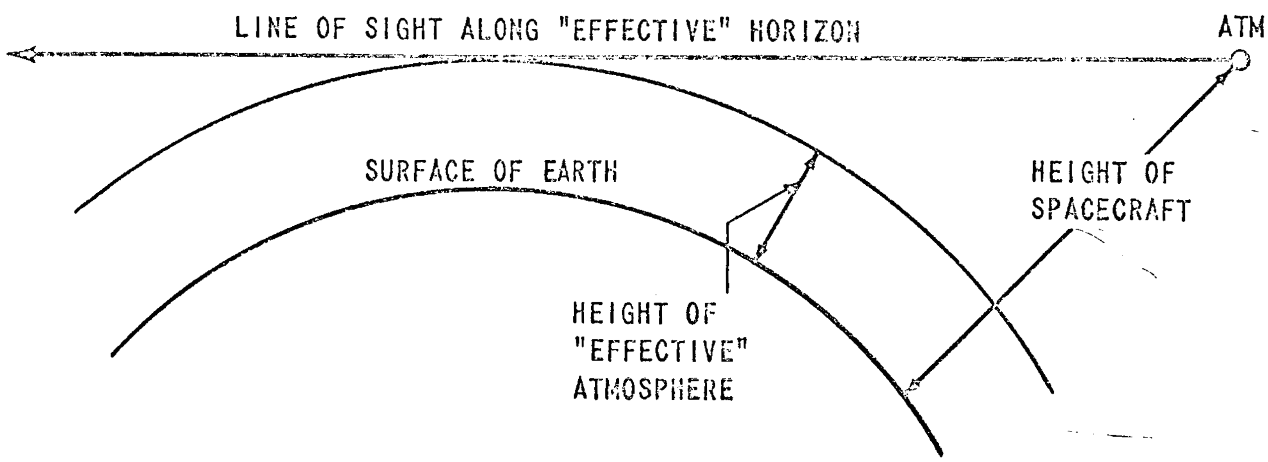

FIGURE 1 - GEOMETRY OF LINE-OF SIGHT TANGENT TO "EFFECTIVE" EARTH ATMOSPHERE

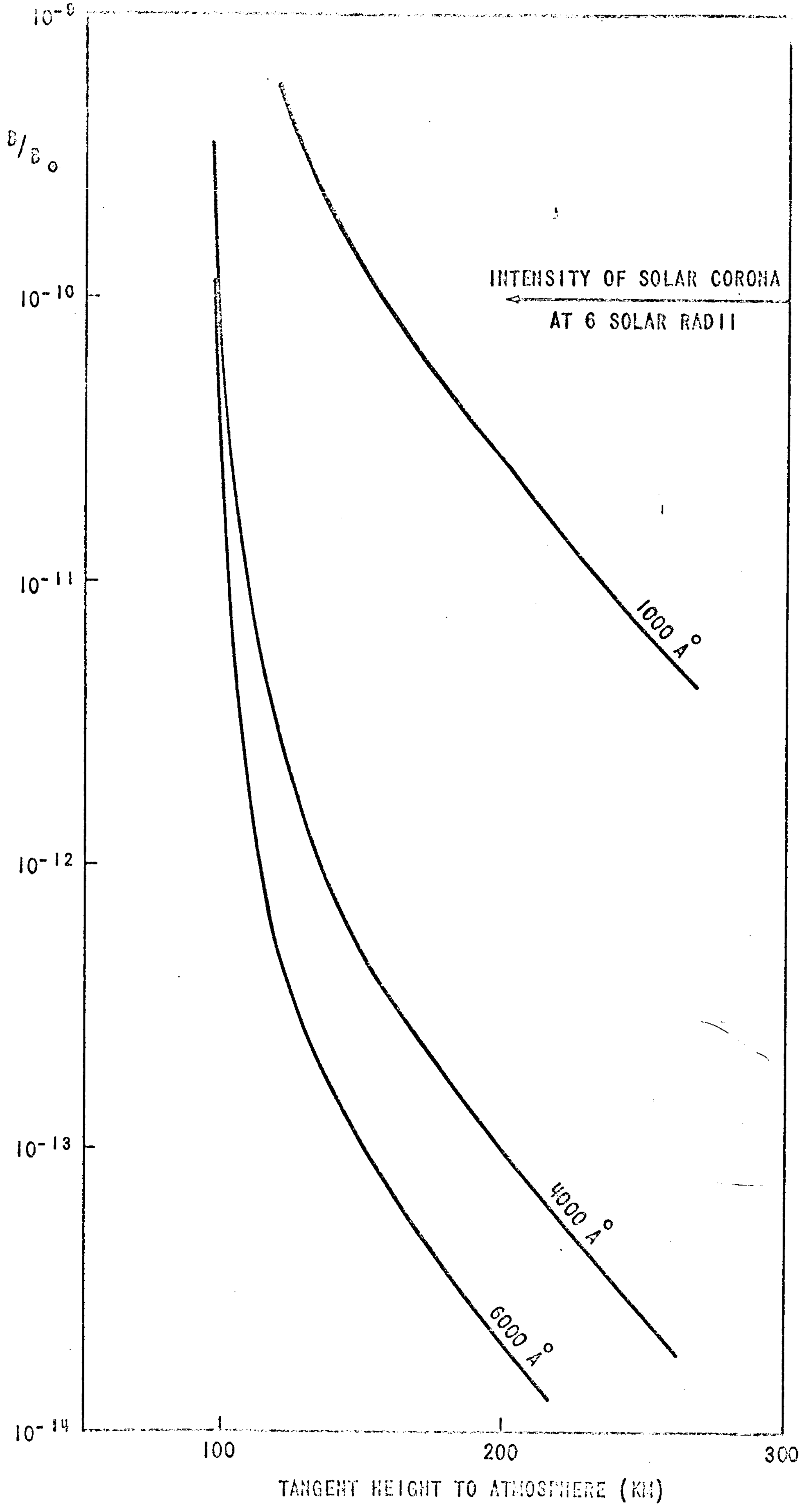

FIGURE 2 [illegible] BY EARTH RESIDUAL ATMOSPHERE FO[illegible] ANGLE NEAR 0°

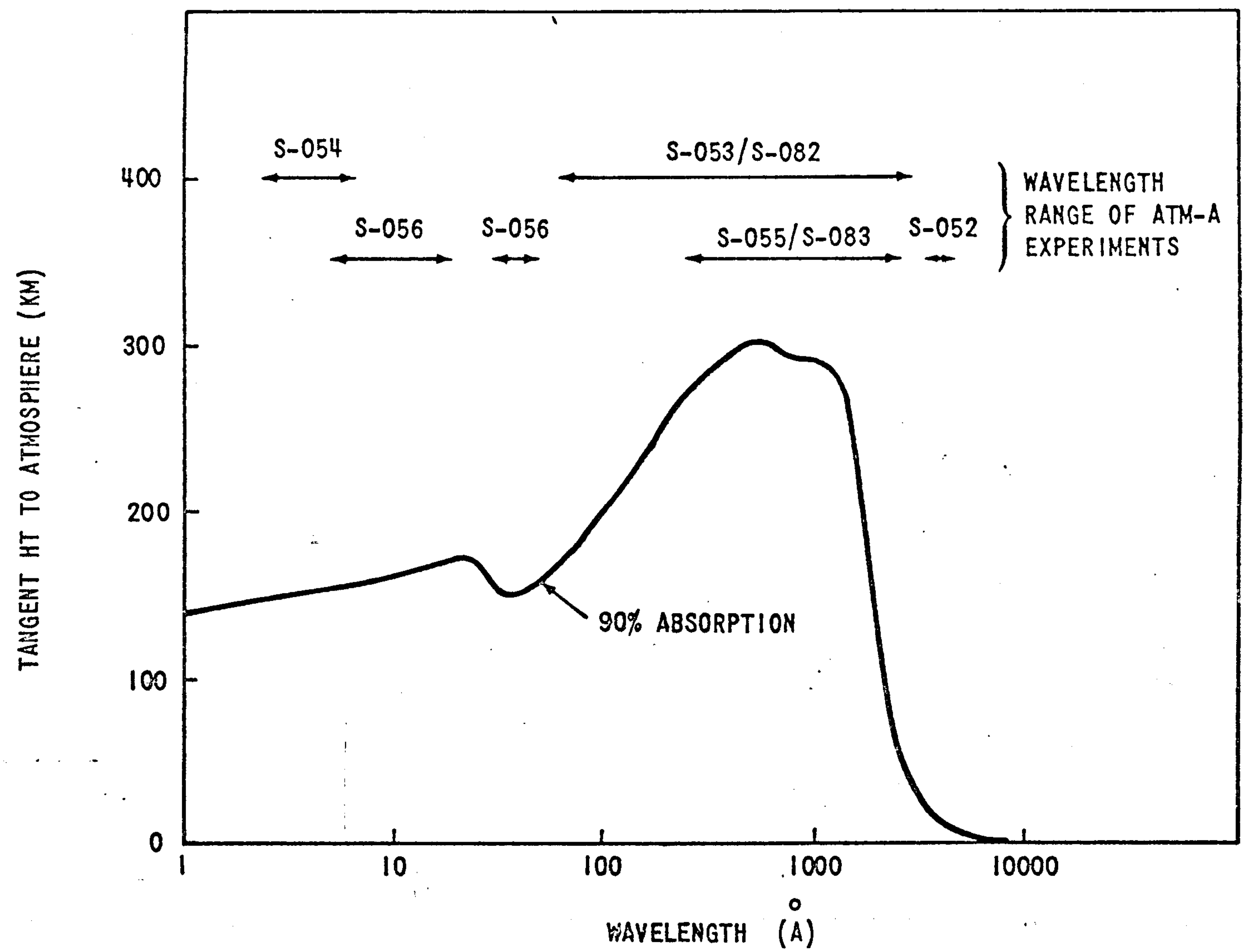

FIGURE 3 - EFFECTIVE HEIGHT OF ATMOSPHERE FOR MOLECULAR ABSORPTION

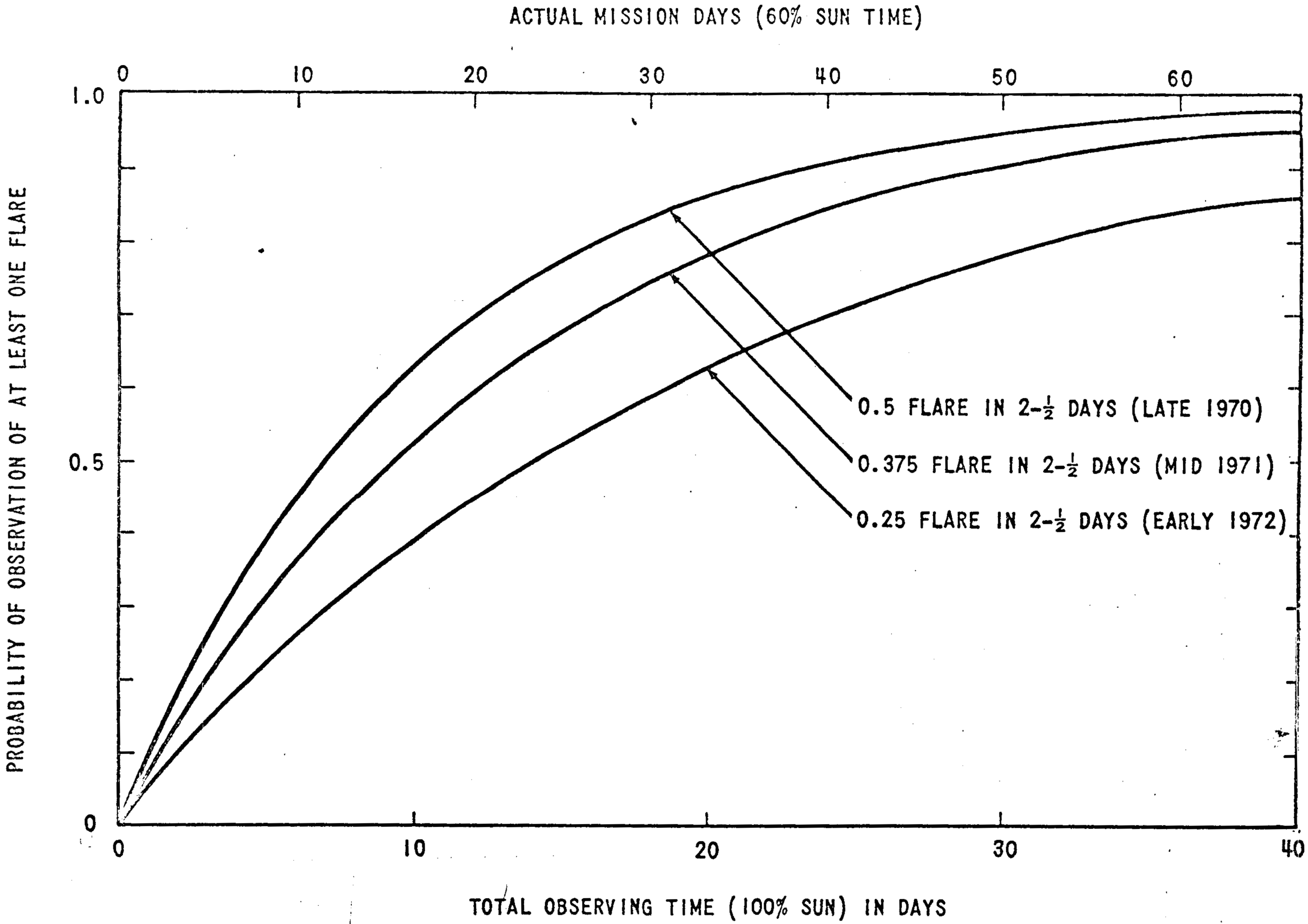

FIGURE 4 - PROBABILITY OF OBSERVING AT LEAST ONE CLASS 2 FLARE

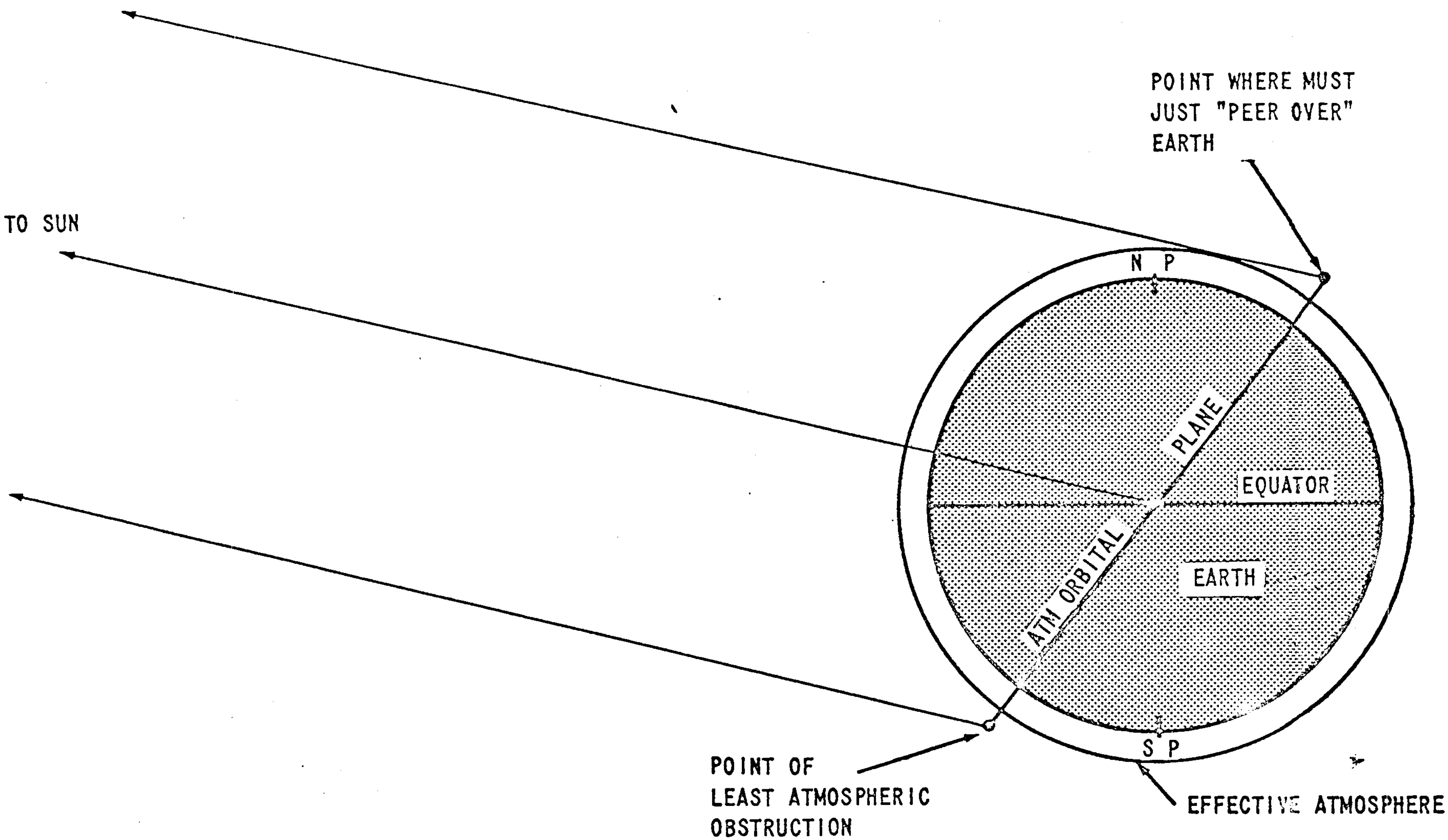

FIGURE 5 - GEOMETRY OF JUST "PEERING OVER" EARTH,
SHOWN FOR TIME NEAR SUMMER SOLSTICE

BELLCOMM, INC.

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